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Crystals of ice on plants.

J. CHRISTIAN BAY.

That ice crystals are formed on the surface of plants under certain conditions of weather and surroundings, as has been noticed lately by Profs. L. F. Ward and D. T. MacDougal, is by no means little noticed. In the winter and spring of 1892 and 1893, these crystals were not unfrequent in Tower Grove Park and the adjacent fields in St. Louis, and I observed this phenomenon also in Europe, in the Botanic Garden, Copenhagen, as far as I remember, in the winter of 1887–88.

Supposing that the phenomenon has been sufficiently outlined by the two first named observers[1], I add the following references to those named by MacDougal.[2]

James D. Dana mentions[3] that he has found, on cold mornings in spring and autumn, thread-like ice-crystals appended vertically to the stems of trees. Papers concerning the same subject are:

R. CASPARY, Auffallende Eisbildungen auf Pflanzen. Botan. Zeitung **12:** 665. 1854. H. HOFFMANN, Pflanzenklimatologie 329. 1857. HUGO VON MOHL, Botan. Zeitung **18:** 15, 16. 1860. J. SACHS, Krystallbildungen bei dem Gefrieren. Berichte d. kgl. Sächs. Akad. d. Wiss. zu Leipzig. Math.-phys. Cl.—:1. 1860. C. NÆGELI, Ueber die Wirkungen des Frostes auf die Pflanzenzellen. Sitzungsber. d. Münchener-Acad. d. Wiss. Math.-phys. Cl., 9 Februar, 1861.

The communication of Sachs is, of course, classical. It should be remembered that H. de Vries and H. Müller-Thurgau have also been working with the influence of cold upon plant cells; likewise Goeppert.

a. Plants on which ice-crystals have been observed.

Conyza bifrons L. (Pluchea bifrons DC.) [S. Elliott, 1824.]
Carduus sp. [Herschel, 1833.]
Heliotropium sp. [Herschel, 1833.]; H. peruvianum (Bouché and Caspary, 1854.)

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[1] See BOT. GAZ. **18:** 183. 1893.—Science—: 351. 29 D 1893.

[2] Cf. also Quarterly Bull., Univ. of Minn. **2:** 30–31.

[3] Manual of Mineralogy, 46. Ed. 2, New Haven and Philad., 1849.

Cunila Mariana [Darlington, 1837; John Le Conte, 1850; L. F. Ward, 1893; MacDougal, 1893; Atkinson, 1885-6. (see Bot. Gaz. **19:** 40-42. 1894.)]

Pulchea camphorata DC. [John Le Conte, 1850.]

Helianthemum Canadense [Eaton and Bigelow; publ. 1837 by Darlington.]

Lantana aculeata, Tagetes Bonariensis, Perilla arguta, Alonsoa incisifolia, Cuphea cordata, C. tubiflora, C. platycentra, Manulea oppositifolia, Calceolaria perfoliata [Bouché and Caspary, 1854.]

Viburnum Tinus [Hoffmann, 1857.] (?) Vernonia sp. [Atkinson, 1885-6.]

Aucuba sp. [Hoffmann, 1857].

Gymnocladus sp., Ailanthus sp , Juglans sp , Asimina triloba, Paulownia; leaves. [von Mohl, 1860.]

Rhamnus sp., Amygdalus communis [Bay and Jensen, in scheda, 1887-88.]

The splitting of wood and the appearance of ice-crystals in the fissures are well known phenomena to tree-planters. In twenty-seven plants, the crystals have been hitherto observed; only those who do not possess sufficient knowledge of the literature will believe that a re-discovery has been made.

The occurrence of similar ice-crystals on the ground is well known in Germany where the crystals are called "Kammeis" (comb-ice); it has been investigated by J. Le Conte, von Mohl, Sachs, Hoffmann, and Caspary.

The many observations on sections of plants, made by Sachs, Nägeli, H. de Vries (Botan. Zeitung **37:** 649. 1879), and by H. Müller-Thurgau (Landw. Jahrb. **9:**) should be mentioned in this connection, only because they afford an opportunity of forming an opinion of the causes of these phenomena.[4]

b. Forms of the crystals.

1. Single ice-columns on the surface [Elliott, Hoffmann, Sachs, Bouché and Caspary]; id. on the surface of root-sections of *Beta* [Sachs; see also Bonnet, Usage des feuilles, p. LXXXII. 1754.]

2. Ice-threads united in sheet crystals [Herschel, Dana, Le Conte, Bouché and Caspary, Ward, MacDougal, Bay and Jensen].

3. Crystals of ice united and forming a layer on the surface; (*a*) under the bark of dead trunks, [Herschel], (*b*) of living trunks [Caspary], (*c*) on the fresh surface of the leaf-pulvinus of falling leaves [von Mohl], (*d*) on the surface of sections [Sachs, Nägeli, de Vries, Müller-Thurgau.]

In consequence of this, MacDougal's results one and two (l. c., p. 351) are premature, and cannot be maintained, since they do not represent all of the observations hitherto made.

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[4] On the temperature of perennial plants in winter see Russell, Bot. Gaz. **14:** 216-222. 1889, and J. Le Conte, Am. Jour. Sci. II. **13:** 84-92, 195-206. 1852.

c. Formation of crystals.

1. The form and fabric of the crystals indicate that the latter grow, and that they are somatropic. The end of the crystals were first formed, and as the column grew, the primary ice-layers were pushed out into the places where they are afterwards found.

2. The central parts of the water-supply layers do not freeze.

3. The formation of the crystals does not result from the organic nature of the substratum; it depends entirely upon molecular forces.

That capillary forces are active in carrying water from the ground up to where the crystals are formed may be seen *a priori*; but the capillary forces *alone* cannot explain the phenomena here mentioned; the question is much more complicated. The contraction of the cells is one important factor, and the permeability of the membrane is another.

Von Mohl's explanation of the appearance of ice-crystals is "that the cold, before it pervades the branches, first causes a contraction in the outer layers, by this contraction the fluids are driven out into the already formed fissure, and there it freezes." That contraction of the layers in the lower parts of the stem of Cerasus does take place, I observed in the following way. The lower parts of the stem, measuring 10^{cm} in length, and about 4^{cm} in diameter was cut off from the rest of the young tree, and kept for three days at a temperature of 18° C. On the fourth day this piece, which had been hitherto kept in wet rags, was dried and placed outside the window where the temperature measured −5° C. After a while big drops of fluid were observed on the cut surface of both ends, covering the entire surface; this fluid rapidly froze, and formed, in five hours, a layer of ice in the place where it had been forced out. A similar experiment was made by von Mohl on Rhamnus. (Cf. Sachs, l. c., 14). The ice-column at the ends of the stem were of a slight white color; they contained a great number of minute air-bubbles.

While Atkinson thinks "that there is a degree of root activity which furnishes the necessary water," and that "a specific variation in the root activity of different plants as related to different temperatures" is a factor in the development of the crystals, Mac Dougal is of the opinion that capillary forces are the only active agents. In regard to the first opinion, it is no doubt remembered that Sachs viewed the matter thus: "Jede Kraft, welche sehr langsam und continuirlich ein Austreten des Wassers im Sinne der Imbibition bewirkt, kann die Krystallbildung befördern, solche Kräfte sind die Contraction des Gewebes, der von den Wurzeln aus stattfindende Saftdruck." The older experiments of Sachs, as well as the latest investigations of Strasburger and especially of Schwendener[5] show that we know very little of the means by which water ascends to the middle and the higher parts of trees. Yet sheet-crystals are found at a considerable distance from the bases of the stems. As to the specific variations surmised by Atkinson, no record of experiments concerning them can be found in my lists of literature.

Capillary forces alone would hardly be able to supply the crystals, especially those on branches of trees, etc.; the old experiments by Montgolfier and Jamin, and the numerous later experiments with Jamin's chain prove this. It is well known that in capillary spaces filled with air and water, the latter does not move to any great extent.

For these reasons, and from the above mentioned freezing experiment, it becomes evident that the exudation of water from cut surfaces is in the first place caused by the contraction of the cells and tissues; we further know that cold produces a power of filtration in the membranes greater than under normal conditions of temperature. In cold, only a very slight pressure will be necessary to make the fluid appear at the ends of the wood. As far back as 1859, this was proved by Sachs (l. c., 39).

We have seen that the sheet-crystals are not only formed in the basal part of the stem, but that they are also found on branches of trees. Assuming root-pressure as one of the water-supplying agencies, we consider it quite remarkable that this should not be active in some cases; in other cases, however, no root-pressure can, for obvious reasons, occur.

Schwendener's investigations point towards "Triebkräfte besonderer Art" in the stem, and, as the specific nature of these forces is unknown, it is most safe to say that any agency which is able to force water upwards through the stem can supply the ice-crystals with water.

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[5] Sitzungsberichte der Akademie der Wissenschaften zu Berlin —: 561, 1886, and ibid, October 26, 1893.—I may add that it is four years since I saw Le Conte's paper; at present I have access only to the review in the "Annals of Scientific Discovery," ed. by D. A. Wells, Boston 1851, p. 157–160.

d. Conditions of formation of crystals.

From what has been said it appears that the conditions for the formation of the ice-crystals are:

1. The temperature must be above zero in the soil surrounding the roots of the plant [Le Conte and Sachs].
2. The temperature of the central parts of the water-conducting tissues must be above zero.
3. The soil must be sufficiently charged with water.

Summary.

The cold causes a contraction of the tissues all over the plant, and consequently the turgescence is very much diminished, as well as the permeability of the cell-walls to water. As the contents of the peripheral ends of the medullary rays freeze, expand, and are pressed forward, the stem splits in the place where it affords the least resistance, and the ice forms a layer covering the whole surface of the wound. The pressure from inside supplies water, the latter being drawn up by capillary forces.

Assuming that the freezing of the water in the ends of the medullary rays was, alone, the cause of the splitting of the stem, this explanation would be insufficient to explain the whole process, for, in many plants, the freezing does not cause the splitting and subsequent exudation from the cells.

It has been proved (Sachs, Müller-Thurgau, De Vries) that the coefficient of contraction is different in the different tissues, and it may be assumed that different plants (even different individuals of the same species or different parts of the same plant) have a different coefficient. MacDougal supposes that plants with large and numerous vessels and thin-walled cells in the medullary rays are especially adapted to form sheet-crystals. It is quite sure that such plants have a larger coefficient of contraction than other plants.

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[Since the above article was written, I have found a quite interesting note entitled "Frost, and the Cunila Mariana L., or dittany," by J. Stauffer, Mount Joy, Penn'a, in The Horticulturist and Journal of Rural Art; **7**: 73–74. New York, 1857. On December 6, 1856, Mr. S. was passing near the Willistown Baptist Meeting House, in Chester co., Pa. Here, he found the ice crystals: "What, however, amply recompensed me for the attention bestowed, was the discovery that this plant is peculiar, and is truly a *frost plant* far exceeding the *Helianthemum Canadense*, or frost weed, as it is popularly called, from the fact that, late in autumn, crystals of ice shoot from the cracked bark at the root. Our *Cunila* has attached to the stem a shell-work of ice, of a pearly whiteness, beautifully striated, sometimes, like a series of shells one in another—at others curved round on either side of them like an open, polished, bi-valve; then, in others, again, curled over in every variety of form, like the petals of a tulip. No other herb or grass had any such frost-work around them; while at least fifty specimens of the *Cunila* were so ornamented. The root manifested a vigorous young bud underground."—BAY.]